2009

Datasets of odontocete sounds annotated for developing automatic detection methods

Mellinger, David K.

Monterey, California. Naval Postgraduate School

NPS-OC-09-008

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Datasets of odontocete sounds annotated for developing automatic detection methods

by

David K. Mellinger

July 2009

Approved for public release; distribution is unlimited.

Prepared for: CNO(N45), Washington, D.C.

THIS PAGE INTENTIONALLY LEFT BLANK

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

Daniel T. Oliver
President

Leonard A. Ferrari
Executive Vice President and
Provost

This report was prepared for CNO(N45), Washington, D.C.
and funded by CNO(N45), Washington, D.C.

Reproduction of all or part of this report is authorized.

This report was prepared by:

David K. Mellinger
Associate Professor
Oregon State University

Reviewed by:

Jeffrey Paduan
Department of Oceanography

Released by:

Karl Van Bibber
Vice President and Dean of Research

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** July 2009	**3. REPORT TYPE AND DATES COVERED** Technical Report, 1 July 2007 – 28 February 2009

4. TITLE AND SUBTITLE: Title (Mix case letters) Datasets of odontocete sounds annotated for developing automatic detection methods	**5. FUNDING NUMBERS** N00244-07-1-0005
6. AUTHOR(S) David K. Mellinger	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Cooperative Institute for Marine Resources Studies, Oregon State University, 2030 SE Marine Science Dr., Newport, OR 97365	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Sponsoring Agency: CNO(N45), Washington, D.C. Monitoring Agency: Department of Oceanography, Naval Postgraduate School, 833 Dyer Road, Monterey, CA 93943-5122	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER** NPS-OC-09-008

11. SUPPLEMENTARY NOTES The views expressed in this technical report are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT	**12b. DISTRIBUTION CODE**
Approved for public release; distribution is unlimited.	

13. ABSTRACT *(maximum 200 words)*

This report documents the progress to date of this project to (1) collect recordings of beaked whales and other odontocete species, (2) annotate the collected sound files to make them useful to researchers working on automatic call detection and classification, (3) make them publicly available in an archive on the Internet (www.mobysound.org), and (4) use them in developing automatic detection algorithms and software. Among other things, one important development from this project has been the invention of a method known as Energy Ratio Mapping Algorithm (ERMA) for detecting clicks of beaked whales and other odontocetes.

A journal paper and numerous presentations about (and using recordings from) this project have been published and presented. Copies of the abstracts of these publications and presentations are included in this report.

14. SUBJECT TERMS MobySound, odontocete, acoustic archive, automatic call detection, automatic call classification, ERMA.	**15. NUMBER OF PAGES** 30
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

THIS PAGE INTENTIONALLY LEFT BLANK

Contents

List of Figures

Datasets of odontocete sounds annotated for developing automatic detection methods

Final report

submitted pursuant to award number N00244-07-1-0005

Dr. David K. Mellinger
Cooperative Institute for Marine Resources Studies
Oregon State University
2030 SE Marine Science Dr.
Newport, OR 97365

Project Overview

Environmental laws including the Endangered Species Act, the Marine Mammal Protection Act, and the National Environmental Policy Act, as well as intense public concern, compel the Navy to conduct its research and operations so as to minimize impacts on marine mammals and to mitigate any adverse impacts those operations may have. For these reasons, it has become important for the Navy to monitor the occurrence and behavior of marine mammals during research and operational activities. For over fifteen years, acoustic methods have been increasingly used for marine mammal research, monitoring, and mitigation, in part due to the greater availability of the necessary hardware and software, and in part because of some perceived advantages: the ability to detect animals underwater, to work at night and in poor weather, and to record the relevant signals and post-process them (if necessary). Acoustic signals used for marine mammal studies are typically either recordings made by autonomous hydrophones [Worcester *et al.* 1995; Fox *et al.* 2001; Clark *et al.* 2002], shore-cabled hydrophones or hydrophone arrays, both military and civilian [Costa 1993; Nishimura and Conlon 1994; Clark 1994; Vents 2005], or sounds captured in real time from towed arrays or expendable sonobuoys during ship-based surveys [*e.g.*, Barlow and Taylor 2005]. Due to advances in technology and decreases in cost, equipment for capturing acoustic data is becoming increasingly widespread, often resulting in data collection abilities outpacing the analysis abilities of many of those collecting the data.

This glut of data is often analyzed using automatic call detection software. Such systems process real-time or recorded data to find times when calls of interest occur. (Here, "call" is used in a generic sense to mean sound produced by an animal, rather than in the narrower technical interpretation used in animal behavior research.) A variety of methods have been developed for detecting and classifying animal sounds; in marine sciences, most of these have been for detecting low-frequency sounds of baleen whales. Although this has been useful, baleen whales comprise only a small fraction of all cetaceans – 14 known species out of a total of roughly 85 – and an even smaller fraction of all marine mammals. In addition, the issues of greatest public concern, and greatest possible impact on Navy operations, center on the threat to odontocetes, especially beaked whales. Beaked whales-- members of the family *Ziphiidae*, including the genera Mesoplodon, Ziphius, Hyperoodon, Berardius, and others-- have stranded in places and times associated with Naval sonar use [Frantzis 1998; NMFS 2001; Fernández *et al.* 2005; Aguilar de Soto *et al.* 2006], and have attracted intense interest from management agencies, conservation organizations, and the public. For these reasons, it is incumbent on the Navy to detect odontocetes in general, and beaked whales in particular, when performing research, training and readiness exercises, ship shock trials, and other activities potentially disruptive to these species. Development of high-performing automatic detection methods for beaked whales and other odontocetes is now imperative.

To further the development of detection methods for odontocetes, it is helpful to have standardized training and testing datasets. Such datasets have been used widely in the automatic speech recognition (ASR) research community [*e.g.*, DARPA 1990, Garofolo *et al.* 1991, Hirsch and Pearce 2000], as they provide a consistent benchmark on which to test and compare recognition methods. An analogous dataset for use in odontocete call detection research would assist the field in much the same way. Preliminary efforts to build such datasets for baleen whale detection have been made [Mellinger and Clark 2006; Desharnais *et al.* 2004]; but before this project, no datasets were widely used for odontocete sounds.

The aims of this project were to collect recordings of beaked whales and other odontocete species, annotate these sound files to make them useful to researchers working on automatic call detection and classification, make them publicly available in an archive on the Internet, and use them in developing automatic detection algorithms and software. The web site for this archive is called MobySound, and is now hosted at www.mobysound.org.

In more detail, project tasks were as follows:

(A) Find any new beaked whale recordings, and solicit contributions to the archive.
Milestone: New sets of beaked whale recordings added to the MobySound archive.

(B) Collect the above recordings from researchers.
Milestone: New beaked whale recordings in our laboratory at OSU in digitized form.

(C) Annotate recordings and make the recordings and metadata available on the web.
Milestone: New beaked whale recordings and metadata available on the web.

(D) Identify recordings of click sounds of other odontocete species.
Milestone: A list of recordings of the selected odontocete species.

(E) Obtain the recordings listed in Task D.
Milestone: Recordings in hand.

(F) Annotate the recordings obtained in task D.
Milestone: Annotated recordings.

(G) Hire a postdoc to develop methods to detect and classify the clicks of these species.
Milestone: A start at building trained, tested, and quantitatively measured detection/classification methods; and a postdoc in training at marine mammal sound analysis, detection, and classification.

(H) Dissemination. Prepare and submit article(s) for publication in scientific journals. In addition, present the results of this work at scientific conferences and other meetings.

Results

The results by task are as follows:

(A) **[Find beaked whale recordings.]** This has been an on-going effort since the start of this project. Some recordings were found, collected, and annotated; these are listed in Tasks B and C just below. The table of extant un-annotated beaked whale recordings available to be added to the archive is included as Appendix 1(b). In addition, the website for the MobySound archive has hosted the datasets for the International Workshops on the Detection, Classification, and Localization of Marine Mammals using Passive Acoustics, of which there have been three to date. The third of these workshops (held in 2007 in Boston) was focused on beaked whales. The datasets from all three of these workshops are now available on the MobySound web site.

(B,C) **[Collect and annotate beaked whale recordings.]** This was done, and recordings from four species of beaked whales are now in the archive. All collected recordings were annotated to indicate the locations of calls of interest. Appendix 1(a) shows these recordings; the beaked whale species are *Ziphius cavirostris, Mesoplodon densirostris, Berardius bairdii,* and *Berardius arnuxii*.

(D) **[Find other odontocete recordings.]** This has been an on-going effort since the start of this project. The table of extant recordings of other odontocetes available to be added to the archive is included as Appendix 1(b).

(E,F) **[Collect and annotate recording of other odontocetes.]** This was done, and recordings from several other odontocete species are now in the archive. All collected recordings were annotated to indicate the locations of calls of interest. Appendix 1(a) shows these recordings; the other odontocete species are *Globicephala macrorhynchus, Grampus griseus, Steno bredanensis, Physeter macrocephalus,* and *Stenella* spp.

(G) **[Postdoc to develop new detection methods.]** A postdoctoral research associate, Dr. Holger Klinck, was hired to develop detection methods and apply them for monitoring and mitigation tasks. Dr. Klinck and I (Mellinger) invented and developed a method known as Energy Ratio Mapping Algorithm (ERMA) for detecting clicks of beaked whales and other odontocetes. ERMA has been presented at several conferences and meetings (see Klinck references in Task H, below), has been implemented in the low-power processing environment of the Acoustic Seaglider™, and is currently being prepared for sea trial in summer 2009.

(H) **[Dissemination.]** The MobySound archive was moved to a new host for faster access. In addition, new web pages for MobySound were developed, and may be seen at www.mobysound.org. An image of the front page of this website is shown in Appendix 2.

In addition, a journal paper and a number of presentations about this project and using recordings from this project have been published and presented. Copies of the abstracts of these publications and presentations are included (in this order) as Appendix 3.

Mellinger, D. K. 2008. A neural network for classifying clicks of Blainville's beaked whales (*Mesoplodon densirostris*). *Canad. Acoust.* **36(1)**:55-59.

Klinck, H., and D. K. Mellinger. 2009. A real-time detection system for odontocete echolocation clicks in the low-energy processing environment of an acoustic glider. *J. Acoust. Soc. Am.* **125(4)**: 2548(A).

Küsel, E. T., D. Mellinger, L. Thomas, T. A. Marques, D. J. Moretti, and J. Ward. 2009. Beaked whale density estimation from single hydrophones by means of propagation modeling. *J. Acoust. Soc. Am.* **125(4)**: 2589.

Klinck, H., D. K. Mellinger, S. Heimlich, and S. Nieukirk. 2008. The Energy Ratio Mapping Algorithm (ERMA): A tool to improve the energy-based detection of odontocete clicks. *Book of Extended Abstracts,* **Second International Conference on Acoustic Communication by Animals**: 119-120.

Mellinger, D. K., H. Klinck, S. Heimlich, and S. Nieukirk. 2008. Annotated odontocete recordings for developing automated detection and classification methods. *J. Acoust. Soc. Am.* **123(5)**: 3362(A).

Roch, M. A., H. Klinck, D. K. Mellinger, M. S. Soldevilla, and J. A. Hildebrand. 2008. Comparison of feature extraction methods for the identification of odontocete species based upon echolocation clicks. *J. Acoust. Soc. Am.* **123(5)**: 3100(A).

Heimlich, S. L., D. K. Mellinger, and S. L. Nieukirk. 2007. MobySound for odontocetes: An annotated archive of sounds automated detection of odontocete vocalizations. **Proc. 15th Biennial Conf. Biol. Mar. Mamm.**, Cape Town.

Mellinger, D. K. 2007. A comparison of methods for detecting sounds of Blainville's beaked whales (*Mesoplodon densirostris*). *Presentation with abstract,* **3rd Intl. Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics**, Boston.

Mellinger, D. K., S. L. Heimlich, S. L. Nieukirk, D. J. Moretti, and N. A. DiMarzio. 2007. An annotated archive for detection of toothed cetacean sounds: MobySound for odontocetes. *Presentation with abstract*, **3rd Intl. Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics**, Boston.

Acknowledgments

Thanks to all the contributors of recordings shown in Appendix 1. Thanks also to Sara Heimlich for assistance with an initial version of this report.

References

Aguilar de Soto, N., M. Johnson, P. T. Madsen, P. L. Tyack, A. Bocconcelli, and J. F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? *Mar. Mamm. Sci.* **22**: 690-699.

Barlow, J., and B. L. Taylor. 2005. Estimates of sperm whale abundance in the northeastern temperate Pacific from a combined acoustic and visual survey. *Mar. Mamm. Sci.* **21**: 429-445.

Clark, C. W. 1994. Application of U.S. Navy underwater hydrophone arrays for scientific research on whales. ***In:*** *Scientific Report*, **International Whaling Commission 44**: 1-12.

Clark, C. W., F. Borsani, and G. Notarbartolo di Sciara. 2002. Vocal activity of fin whales, *Balaenoptera physalus*, in the Ligurian Sea. *Mar. Mamm. Sci.* **18**: 286-295.

Costa, D. P. 1993. The secret life of marine mammals: novel tools for studying their behavior and biology at sea. *Oceanography* **6(3)**: 120-128.

DARPA. 1990. The DARPA TIMIT acoustic-phonetic continuous speech corpus. *Technical Report PB91-505065*, **National Inst. Standards Tech.**, Gaithersburg, MD.

Desharnais, F., M. H. Laurinolli, D. J. Schillinger, and A. E. Hay. 2004. A description of the workshop datasets. *Can. Acoust.* **32**: 33-38.

Fernández, A., J. F. Edwards, F. Rodríguez, A. E. de los Monteros, P. Herráez, P. Castro, J. R. Jaber, V. Martín, and M. Arbelo. 2005. ``Gas and Fat Embolic Syndrome" involving a mass stranding of beaked whales (family *Ziphiidae*) exposed to anthropogenic sonar signals. *Veterinary Pathology* **42**: 446-457.

Fox, C. G., H. Matsumoto, and T. K. A. Lau. 2001. Monitoring Pacific Ocean seismicity from an autonomous hydrophone array. *J. Geophysical Res.* **106(B3)**: 4183-4206.

Frantzis, A. 1998. Does acoustic testing strand whales? *Nature* **392**: 29.

Garofolo, J. S., L. F. Lamel, W. M. Fisher, J. G. Fiscus, D. S. Pallett, and N. L. Dahlgren. 1991. The DARPA TIMIT acoustic-phonetic continuous speech corpus on CDROM. *Technical Report PB91-100354*, **National Inst. Standards Tech.**, Gaithersburg, MD.

Hirsch, H. G., and D. Pearce. 2000. The AURORA experimental framework for the performance evaluations of speech recognition systems under noisy conditions. *ISCA ITRW Workshop* **Automatic Speech Recognition: Challenges for the Next Millennium**, Paris, Sept. 2000.

Mellinger, D. K., and C. W. Clark. 2006. MobySound: A reference archive for studying automatic recognition of marine mammal sounds. *Applied Acoustics* **67**: 1226-1242.

Nishimura, C. E., and D. M. Conlon. 1994. IUSS Dual Use: Monitoring whales and earthquakes using SOSUS. *Mar. Tech. Soc. J.* **27(4)**: 13-21.

NMFS. 2001. Bahamas Marine Mammal Stranding Event of 15-16 March 2000. *Technical report*, **National Mar. Fisheries Service**, Washington, DC.

Vents. 2005. Acoustic monitoring program: Pioneer Seamount. *Web site* **http://www.pmel.noaa.gov/vents/acoustics/pioneer.html**, NOAA/PMEL Vents Program.

Worcester, P. F., K. R. Hardy, D. Horwitt, and D. A. Peckham. 1995. A deep ocean data recovery module. *IEEE* **Oceans '95 Proc.**: 1225-1231.

Appendix 1:

Status summary of recordings in and available to the archive.

Species	Common Name	Region	N sounds	N files	N (s)	Source *
Appendix 1(a). CURRENT						
Mysticetes						
Balaena mysticetus	bowhead whale	northern Alaska	589			NOAA/CIMRS
Eubalaena australis	southern right whale	South Africa	67			
Eubalaena glacialis	North Atlantic right whale	North Atlantic				Cornell Univ.
Eubalaena japonica	North Pacific right whale	Bering Sea	38			NOAA/CIMRS
Balaenoptera acutorostrata	minke whale	North Atlantic	178			NOAA/CIMRS
Balaenoptera edeni	Bryde's whale	eastern tropical Pacific	1402			NOAA/CIMRS
Balaenoptera musculus	blue whale	North Atlantic	405	9		NOAA/CIMRS
Balaenoptera physalus	fin whale	North Atlantic	3066			NOAA/CIMRS
Megaptera novaeangliae	humpback whale	North Atlantic	2310			NOAA/CIMRS
Odontocetes – beaked whales						
Berardius arnuxii	Arnoux's beaked whale	Antarctic	3379	3	8409	U. New S. Wales
Berardius bairdii	Baird's beaked whale	North Pacific		21	7233	NMML/UW-APL
		Baja Mexico		60	3600	NMML
		North Pacific		20	7224	NMML/UW-APL
		Baja Mexico				NMML/NOAA
Mesoplodon densirostris	Blainville's beaked whale	AUTEC, N. Atlantic	3637	41	67613	NUWC
		Canary Islands	3000	1	1260	WHOI
		eastern tropical Pacific		3	19.7	NOAA/SWFSC
Ziphius cavirostris	Cuvier's beaked whale	Mediterranean	3137	1	1800	NUWC
Odontocetes - other						
Globicephala macrorhynchus	short-finned pilot whale	AUTEC, N. Atlantic		9	13500	NUWC
Grampus griseus	Risso's dolphin	SCORE, S. Calif.		10	17100	SIO
Stenella sp.	spotted dolphin	AUTEC, N. Atlantic		1	1800	NUWC

Steno bredanensis	rough-toothed dolphin	AUTEC, N. Atlantic	2	3600	NUWC
Physeter macrocephalus	sperm whale	AUTEC, N. Atlantic	3	2790	NUWC

Appendix 1(b). EXTANT: Annotated and available to archive

Mysticetes			
Megaptera novaeangliae	humpback whale	N. Atlantic	OASIS, Inc.
Odontocetes			
Delphinus delphis	short-beaked common dolphin	S. California	SIO
Delphinus capensis	long-beaked common dolphin	S. California	SIO
Physeter macrocephalus	sperm whale	Mediterranean Gulf of Mexico	Univ. Crete Univ. New Orleans

*Abbreviations:

AUTEC	Atlantic Undersea Test and Evaluation Center
CIMRS	Cooperative Institute for Marine Resources Studies
NMML	NOAA National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NUWC	Naval Undersea Warfare Center
SCORE	Southern California Offshore Range
SIO	Scripps Institution of Oceanography
UW-APL	University of Washington, Applied Physics Laboratory
WHOI	Woods Hole Oceanographic Institute

Appendix 2:

Open access website

Appendix 3. Publications and Presentations.

Abstracts of the publications and presentations made as part of this project follow here.

A: Mellinger, D. K. 2008. A neural network for classifying clicks of Blainville's beaked whales (*Mesoplodon densirostris*). Canadian Acoustics **36(1)**: 55-59.

Beaked whales are difficult to detect visually, and researchers have thus proposed using acoustic detection and classification. Because of the large data volumes often involved in acoustic detection and classification, automatic methods are often used. Here a neural network classification method is investigated. Using backpropagation, a feedforward neural network with one hidden layer was trained to classify clicks of Blainville's beaked whales and other odontocetes recorded in the Bahamas. Training and testing data consisted of approximately 1600 Blainville's beaked whale clicks and 3100 clicks from other odontocetes. Networks with 2-10 hidden units were trained and tested, with performance curves (ROC curves) calculated at several levels of signal-to-noise ratio. Results for most networks were quite good when compared with previous classification efforts, with less than 3% errors in both the wrong-classification and missed-call categories. Future work includes testing the network on sounds recorded in different noise backgrounds and from other populations of Blainville's beaked whales, and combining it with a detector and evaluating the joint performance.

B: Klinck, H., and D. K. Mellinger. 2009. ERMA: A real-time detection system for odontocete echolocation clicks in the low energy processing environment of an acoustic glider. *J. Acoust. Soc. Am.* **125(4)**: 2548(A).

This presentation will introduce a real-time system, the energy ratio mapping algorithm (ERMA), for detection of odontocete echolocation clicks. The system has been developed to run continuously over extended periods of time in low-energy processing environments such as acoustic gliders. The detector operates in the time domain and takes advantage of the species-specific differences in the power spectra and inter-click interval of echolocation clicks to minimize the number of false positive detections. We will demonstrate the operation of ERMA using the clicks of beaked whales, family *Ziphiidae*, as example target species. To get information on the performance of ERMA, a comparison with more sophisticated and already established detection systems was conducted. Preliminary results indicate that the developed method is a promising tool to reliably detect echolocation clicks emitted by the Cuvier's beaked whale (*Ziphius cavirostris*) in real time. Ongoing work is focused on implementation of the detector in the Acoustic Seaglider developed by the Applied Physics Laboratory of the University of Washington (APL-UW) and the use of this platform for autonomous passive acoustic monitoring and mitigation of beaked whales and other odontocete species.

<u>C:</u> Küsel, E. T., D. Mellinger, L. Thomas, T. A. Marques, D. J. Moretti, and J. Ward. 2009. Beaked whale density estimation from single hydrophones by means of propagation modeling. *J. Acoust. Soc. Am.* **125(4)**: 2589(A).

> Passive acoustic sonar systems offer many advantages to the study of marine mammals. For density estimation studies, it is important to evaluate the probability of detecting an animal as a function of its distance from the receiving sensor. In this work, acoustic propagation modeling is used to estimate the transmission loss as a function of depth and range between a source whale and a single-hydrophone receiver. The computed transmission loss is compared to ambient noise levels and source level distributions to estimate the detection probability as a function of range. Results will be compared to beaked whale data recorded on bottom-mounted sensors in the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, where the location of clicks is relative to one hydrophone. Source level and beam pattern extracted from digital acoustic tags (DTags) applied to a sample of animals at the same location will also be used in the detection model, and beaked whale spatial density will be estimated. The detection probability function will provide a relevant comparison to the detection function derived empirically from the DTag data by Marques *et al.* (paper submitted to JASA).

D: Klinck, H., D. K. Mellinger, S. Heimlich, and S. Nieukirk. 2008. The Energy Ratio Mapping Algorithm (ERMA): A tool to improve the energy-based detection of odontocete clicks. ***In:*** Book of Extended Abstracts, *Second International Conference on Acoustic Communication by Animals*, pp. 119-120.

Energy-based detection algorithms are commonly used to detect many types of sound signals, including odontocete clicks, in real time. A major advantage of such algorithms is their relatively low computational cost, as they can operate in the time domain. However, for detecting a certain species of odontocete, using a time-domain algorithm often results in a high number of false positive detections caused by clicks of other odontocete species. The energy ratio mapping algorithm (ERMA) was developed to reduce the number of false positive detections while keeping the advantage of low computational cost.

For example, the power spectrum of Cuvier´s (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whale clicks shows a significant rise in energy between approximately 20 and 35 kHz. Thus the ratio between the energies in two frequency bands, one above and one below the rise, is a useful measure for detecting these beaked whale clicks. Calculating such a ratio is computationally simple, as it can be done digitally with a low-order IIR filter, or even in analog hardware.

However, clicks of other odontocete species have energy in these bands and can cause false positive errors. The question arises of how to choose the two frequency bands that will provide the best ability to discriminate between the target species and other odontocetes that are present in a given geographic area. To systematically assess the performance of different ratios, ERMA compares clicks produced by all odontocete species occurring in an area of interest. A number of sample clicks of all species present are collected and used as follows: for each species, ERMA produces a map of average energy ratios at different frequencies by applying a 1/3-octave filter bank to the given click samples and calculating the energy ratio between each possible pair of frequency bands. In a second step, ERMA creates a non-target species map by taking the maximum at each grid point over all maps of species which are not of interest. Finally this latter map is subtracted from the map for the target species. The resulting map-- the ‘discrimination map’-- (1) indicates the best frequency bands for calculating a ratio to detect the target species, and (2) permits estimation of an appropriate detection threshold.

Figure A3.1 gives an example for *Ziphius cavirostris*. Figure A3.1a represents the energy ratio map evaluated from 100 *Ziphius cavirostris* echolocation clicks. The map indicates that the highest energy ratio occurs between the frequency bands with center frequency 37 kHz and 6.1 kHz. Upon consideration of five additional odontocete species (sperm whale, killer whale, pilot whale. Risso’s dolphin and spinner dolphin), ERMA derives the optimum frequency bands for detecting *Ziphius* when these other species may be present: those with center frequencies 37 kHz and 10.1 kHz (Figure A3.1b). By comparing the values at the optimum grid point, 37 kHz/10.1 kHz in both maps, a detection threshold can be estimated: 22 dB - 16 dB = 6 dB.

ERMA allows optimization of the performance of energy-based odontocete click detection by reducing the number of false positive detections caused by non-target species. This is especially helpful for applications in low-power environments, such as acoustic gliders, where sophisticated detection algorithms cannot be operated continuously. However, ERMA works best when used as the first step of a two-step detector; the second step can be a significantly more sophisticated classifier that improves detection performance. Such classifiers are typically quite computationally intensive, and are best used on only a tiny fraction of the input sound signal. As the first step, ERMA chooses only those clicks that have a high likelihood of being from the target species. By reducing the number of clicks which are sent to the second-step classifier, ERMA reduces the overall computational cost of the overall process.

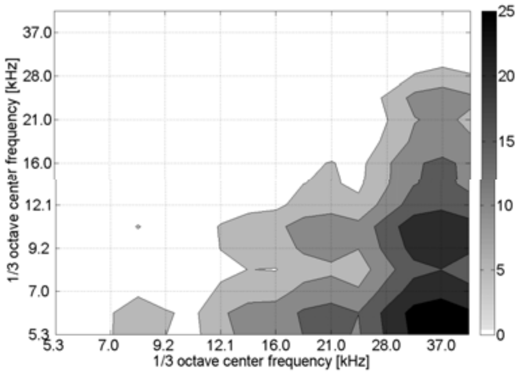

Figure A3.1a: Energy ratios [dB] calculated for *Ziphius cavirostris* (see text).

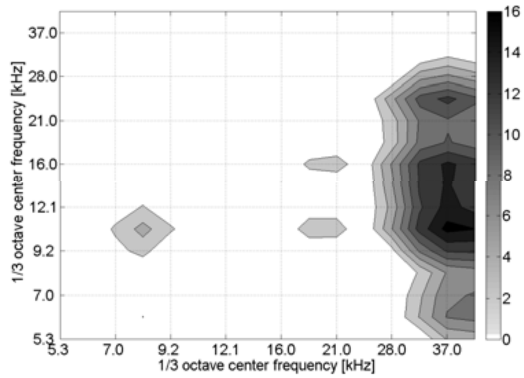

Figure A3.1b: Energy ratios [dB] calculated for *Ziphius cavirostris* under consideration of five additional odontocete species (see text).

<u>E:</u> Mellinger, D. K., H. Klinck, S. L. Heimlich, and S. L. Nieukirk. 2009. Annotated odontocete recordings for developing automated detection and classification methods. *J. Acoust. Soc. Am.* **123(5)**: 3362(A).

A free archive has been developed for research in automatic detection/classification of cetacean sounds. The archive contains many datasets, with each dataset comprising recordings and metadata for a given species and geographic area. This archive differs from other sound archives in three important respects. (1) Recordings are annotated to indicate where in time and frequency the sounds of a given species occur. These annotations are done manually to remove the bias of any automatic detection system. (2) The archive deliberately includes poor-quality recordings, recordings encountered in any realistic detection/classification application. (3) Since performance of detection/classification methods depends heavily on the SNR of target sounds, the archive includes each vocalization's SNR so performance can be effectively represented. Until recently, most recordings in the archive were of baleen whales [Mellinger and Clark 2006, *Applied Acoustics* **67(11)**]. However, datasets for toothed whales and dolphins are now being incorporated. Initial efforts have been focused on beaked whales because of high interest for management and because of the difficulty of visual detection. To date, recordings of Cuvier's, Blainville's, Baird's, and Arnoux's beaked whales have been entered into the archive, as have those of bottlenose whales, pilot whales, and some delphinid species. Further contributions are welcomed.

<u>F:</u> Roch, M. A., H. Klinck, D. K. Mellinger, M. S. Soldevilla, J. A. Hildebrand, and S. Baumann. 2009. Comparison of feature extraction methods for the identification of odontocete species based upon echolocation clicks. *J. Acoust. Soc. Am.* **123(5)**: 3100(A).

Recent work by several groups has shown that odontocete echolocation clicks contain information that can be used to detect or identify specific species. In this study, we compare the relative performance of cepstral and wavelet features on various Pacific Ocean species of odontocetes such as: short-beaked and long-beaked common dolphins, bottlenose dolphins, Risso's dolphins, Pacific white-sided dolphins, spinner dolphins, beaked whales, and melon-headed whales. Comparison of features within different systems is often complicated by the large number of variables unrelated to feature extraction that change between systems. By experimenting within a proven state of the art classification framework, it is possible to make meaningful comparisons of feature extraction performance with respect to common machine learning algorithms such as neural networks, support vector machines, and Gaussian mixture models.

G: Heimlich, S. L., D. K. Mellinger, and S. L. Nieukirk. 2007. MobySound for odontocetes: An annotated archive of sounds automated detection of odontocete vocalizations. *Proc. 15th Biennial Conf. Biol. Mar. Mamm.*, Cape Town.

The MobySound archive [Mellinger and Clark 2006, *Applied Acoustics*] was created to provide open-source sound files and metadata for the development of automatic detectors for cetacean sounds. Publicly available sound archives like MobySound permit different researchers to train and test their detection methods using the same datasets, allowing meaningful comparison between methods. Archives with annotated datasets can provide essential factors for evaluating any detection method. Annotations in MobySound include parameters indicating where, in time and frequency, the sounds of interest occur; this is especially useful for long recordings. Annotations also include a description of the signal-to-noise ratio (SNR) of the target sounds so that detector performance can be adequately characterized. Until recently, MobySound consisted primarily of baleen whale vocalizations, but odontocete vocalizations are now being included. Providing useful datasets of odontocete sounds presents unique challenges and requires different annotations. The non-stereotypical nature of odontocete vocalizations compels accurate visual identification of the sound source. Sound file sizes are commonly very large because odontocete recordings must be made at a high sampling rate to capture the high frequencies. Extremely short vocalizations, especially clicks, require a different technique for characterizing SNR than that used for the much longer baleen whale sounds: SNR is measured by filtering the recording to retain only the frequency band of interest, then measuring the peak-to-peak click level in the time series. MobySound currently contains several thousand annotated clicks of Blainville's beaked whale (*Mesoplodon densirostris*) and Cuvier's beaked whale (*Ziphius cavirostris*). The archive also contains recordings, not yet annotated, of other vocalizations made by these species, and of long-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), pantropical spotted dolphin (*Stenella attenuata*), and rough-toothed dolphin (*Steno bredanensis*). Recordings and annotations of more odontocete species and of whistle vocalizations are planned.

H: Mellinger, D. K. 2007. A comparison of methods for detecting sounds of Blainville's beaked whales (*Mesoplodon densirostris*). *3rd Intl. Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics*, Boston.

Beaked whales have in recent years attracted intense interest from scientists, management agencies, conservation organizations, and the public. In part this is because of the continued lack of scientific understanding of these deep-water animals, and in part because they have stranded in places and times associated with the use of mid-frequency naval sonars. For this reason, the detection of beaked whales has become increasingly important to scientists, to navies, and to conservationists interested in these species. Here we compare methods for detection of Blainville's beaked whale clicks. One technique is pure spectral clustering, statistical clustering applied to the power spectra of successive frames of the input signal. Another, spectrogram correlation, relies on the fact that the clicks have time-frequency structure and can be detected by a time-frequency kernel. The third method is based on a multi-component feature-measurement technique (akin to Fristrup's Acoustat) combined with a tree-based clustering algorithm. The methods' performance is compared on the training and test data provided for the workshop, and performance is characterized as a function of signal-to-noise ratio.

<u>I:</u> Mellinger, D. K., S. L. Heimlich, S. L. Nieukirk, D. J. Moretti, and N. A. DiMarzio. 2007. An annotated archive for detection of toothed cetacean sounds: MobySound for odontocetes. *3rd Intl. Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics*, Boston.

Progress in automatic detection of marine mammal sounds can be enhanced by the availability of datasets of annotated recordings. With datasets openly available and widely used, different researchers can train and test their methods using the same data, allowing meaningful comparison between methods. Annotation is used to indicate where (in time and frequency) within long recordings the sounds of interest occur. It can also indicate the signal-to-noise ratio of the target sounds, so that performance can be characterized by signal-to-noise ratio (SNR)--an essential factor in evaluating any detection method. The MobySound archive [Mellinger and Clark 2006, *Applied Acoustics*] has to date consisted primarily of baleen whale vocalizations, but now it includes sounds of odontocetes. Odontocete sounds present unique challenges for such an archive. These sounds, particularly clicks, are not as distinctive as most stereotypical baleen whale calls, making accurate visual identification of the sound source of paramount importance. Recordings must be made at a high sampling rate to capture the high frequencies of the sounds, leading to sound files of very large size. Characterizing SNR for extremely short sounds, such as odontocete clicks, requires a different technique than that used for the much longer baleen whale sounds: SNR is measured by filtering the recording to retain only the frequency band of interest, then measuring the peak-to-peak click level in the time series. To date, MobySound contains several thousand annotated clicks of Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), long-finned pilot whale (*Globicephala macrorhynchus*), and Risso's dolphin (*Grampus griseus*). More species are anticipated.

Initial Distribution List

1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, VA 22060-6218	2
2.	Dudley Knox Library, Code 013 Naval Postgraduate School Monterey, CA 93943-5100	2
3.	Erin Oleson National Marine Fisheries Service Pacific Islands Fisheries Science Center Honolulu, HI	1
4.	John Hildebrand Scripps Institution of Oceanography University of California La Jolla, CA	1
5.	John Calambokidis Cascadia Research Collective Olympia, WA	1
6.	Greg Schorr Cascadia Research Collective Olympia, WA	1
7.	Erin Falcone Cascadia Research Collective Olympia, WA	1
8.	Ching-Sang Chiu Naval Postgraduate School Monterey, CA	1
9.	Curtis A. Collins Naval Postgraduate School Monterey, CA	1
10.	Thomas A. Rago Naval Postgraduate School Monterey, CA	1

11.	Tetyana Margolina Naval Postgraduate School Monterey, CA	1
12.	Chris Miller Naval Postgraduate School Monterey, CA	1
13.	John Joseph Naval Postgraduate School Monterey, CA	1
14.	Katherine Whitaker Pacific Grove, CA	1
15.	Frank Stone CNO(N45) Washington, D.C.	1
16.	Jay Barlow Southwest Fisheries Science Center, NOAA La Jolla, CA	1
17.	CAPT Ernie Young, USN (Ret.) CNO(N45) Washington, D.C.	1
18.	Dale Liechty CNO(N45) Washington, D.C.	1
19.	Dave Mellinger Oregon State University Newport, OR	1
20.	Kate Stafford Applied Physics Laboratory University of Washington Seattle, CA	1
21.	Sue Moore NOAA at Applied Physics Laboratory University of Washington Seattle, WA	1

22.	Petr Krysl University of California La Jolla, CA	1
23.	Mark McDonald Whale Acoustics Bellvue, CO	1
24.	Ted Cranford Quantitative Morphology Consulting, Inc. AND San Diego State University San Diego, CA	1
25.	Monique Fargues Naval Postgraduate School Monterey, CA	1
26.	Mary Ann Daher Woods Hole Oceanographic Institution Woods Hole, MA	1
27.	Heidi Nevitt NAS North Island San Diego, CA	1
28.	Rebecca Stone Naval Postgraduate School Monterey, CA	1
29.	Melissa Hock Scripps Institution of Oceanography University of California La Jolla, CA	1
30.	Sean M. Wiggins Scripps Institution of Oceanography University of California La Jolla, CA	1
31.	E. Elizabeth Henderson Scripps Institution of Oceanography University of California La Jolla, CA	1

32.	Gregory S. Campbell Scripps Institution of Oceanography University of California La Jolla, CA	1
33.	Marie A. Roch San Diego State University San Diego, CA	1
34.	Anne Douglas Cascadia Research Collective Olympia, WA	1
35.	Julie Rivers Naval Facilities Engineering Command, Pacific Pearl Harbor, HI	1
36.	Jenny Marshall Naval Facilities Engineering Command San Diego, CA	1
37.	Chip Johnson COMPACFLT Pearl Harbor, HI	1
38.	CDR Len Remias U.S. Pacific Fleet Pearl Harbor, HI	1
39.	LCDR Robert S. Thompson U.S. Pacific Fleet Pearl Harbor, HI	1
40.	Jene J. Nissen U. S. Fleet Forces Command Norfolk, VA	1
41.	W. David Noble U. S. Fleet Forces Command Norfolk, VA	1
42.	David T. MacDuffee U. S. Fleet Forces Command Norfolk, VA	1

43.	Keith A. Jenkins Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
44.	Joel T. Bell Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
45.	Mandy L. Shoemaker Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
46.	Anurag Kumar Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
47.	Merel Dalebout University of New South Wales Sydney, Australia	1
48.	Robin W. Baird Cascadia Research Collective Olympia, WA	1
49.	Brenda K. Rone National Marine Mammal Laboratory Seattle, WA	1
50.	Phil Clapham National Marine Mammal Laboratory Seattle, WA	1
51.	Laura J. Morse National Marine Mammal Laboratory Seattle, WA	1
52.	Anthony Martinez NOAA Southeast Fisheries Science Center Miami, FL	1
53.	Darlene R. Ketten Woods Hole Oceanographic Institution Woods Hole, MA	1

54.	David C. Mountain Boston University Boston, MA	1
55.	Melissa Soldevilla Duke University Durham, NC	1
56.	Lisa Munger Scripps Institution of Oceanography University of California La Jolla, CA	1
57.	Karlina Merkens Scripps Institution of Oceanography University of California La Jolla, CA	1